## ONR CONTRACT INFORMATION

### FINAL REPORT

*Contract Title:*         EIGENMODE STATISTICS AND PARTIAL COHERENCE IN THE RESPONSES OF COMPLEX STRUCTURES

*Performing Organization:*     UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

*Principal Investigator:*        RICHARD L. WEAVER   (217) 333-3656(ph);
                                        (217) 244-5707(fax);  r-weaver@uiuc.edu

*Contract Number:*          N00014 - 91 - J1873

*ONR Scientific Officer :*      GEOFFREY L. MAIN
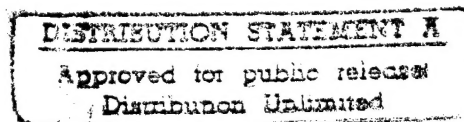                                      Chief of Naval Research
                                      Code 122R3
                                      Balliston Tower One
                                      800 N. Quincy Street
                                      Arlington, Va   22217-5660
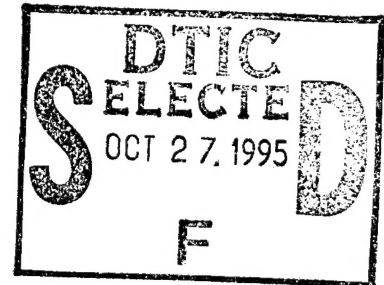
*Research Participants*

                                      P.I. : Professor Richard L. Weaver
                                      Graduate Research Assistant: John Burkhardt,
                                           PhD expected  Summer1995

19951026 100

# SUMMARY OF TECHNICAL RESULTS

## A. Description of scientific research goals

The reliability of statistical theories for the responses of complex structures (*e.g.* Statistical Energy Analysis, and Asymptotic Modal Analysis) is studied by using exact eigenmode statistics in lieu of the usual *ad hoc* assumptions for those statistics. It is intended to investigate the failings of statistical theories for the responses of complex systems, and in particular their predictions for variances, with a view towards learning how to correct these failings by the use of more sophisticated models for modal statistics, in eigenvalue and eigenmode correlations, and in resonance magnitude and width statistics.

The work involves the generation of numerical solutions for the eigenmodes of complex structures and their subsequent statistical analysis. High order statistical theories for the responses of complex structures are developed and the eigenmode statistics employed where called for by the theories. The statistics of numerically generated time-domain solutions are then compared with theory.

## B. Significant results

A large sample of undamped 30x30 and several 50x50 irregular two-dimensional wave equation domains were solved numerically and their solutions scrutinized in regard to eigenmode statistics. Eigenfrequency repulsion and spectral rigidity were confirmed and certain correlations observed between the eigenshapes. The results can be summarized with the statement that the eigenfrequencies have no short range correlations other than those implied by Random Matrix Theory. The mode shapes are nearly independent Gaussian random numbers (with the expected simple Bessel function spatial correlations). They do, however, have an interesting unanticipated long range spectral correlation over frequency differences corresponding to the transit time across the structure. There are no short range spectral correlations in the mode shapes in the interior of the system.

The eigenmodes of generic damped systems were also been scrutinized. An algorithm was pursued which proceeds by extraction of exact solutions to truncated systems, truncated by consideration only of modes within a narrow band of frequencies. We had speculated that these exact solutions will converge quickly to the exact solution to the full original system as the band is widened. We found, however, that convergence was not fast, even for moderate amounts of damping. (For sufficiently small amounts of damping it is well known that the first step in this iteration usually suffices, hence the speculation.) We therefore proceeded to solve for the eigenmodes of damped systems by full numerical diagonalization of state-space formulations of the dynamics. Large numbers of damped systems of sizes up to 28x28 were studied in this way.

Damped systems were found to exhibit slightly weakened spectral rigidity and significantly weakened eigenfrequency repulsion. Thus Random Matrix Theory does *not* correctly predict frequency statistics in damped systems. We have described theoretically why it is that Random Matrix theory should fail here. The statistics of damping rates were also studied, and found to lie in moderate accord with our theoretical predictions.

The work implies that response statistics may be constructed from assumed modal statistics that have less correlation and are less complicated than one might have feared. They are, nevertheless, not trivial and rather different than is usually assumed. The consequences of the observed eigenstatistics for time and frequency domain response statistics were confirmed by numerical simulation in the time domain.

Amongst the heretofore unexpected consequences of the statistics is the occurrence of enhanced backscatter in reverberant systems. We have predicted theoretically, and shown

numerically, an echo-like phenomenon that should be present in all reverberant acoustic systems. Diffuse responses at the position of a transient source were shown to be two to three times stronger than they are elsewhere, even at times long after the source has stopped.

In a tangential thrust of presumed interest to the Structural Acoustics Program at ONR, we noted that Diffuse Field Theory has certain fairly clear consequences for the rate at which subsonic energy is shed from a smooth shell into a surrounding fluid, with corresponding implications for lower bounds on the actual shedding rate of an inhomogeneous shell. The bounds are based on Diffuse Field predictions for the equipartition between flexural and extensional waves and on known shedding rates for extensional waves in plates and flexural waves in shells. We also showed that the method predicts the angular distribution of the shed energy from a smooth shell. This work is being extended to lower frequencies and to more realistic shells in a new ONR project: N00014-94-1-0855.

## C. Plans for future research

Except for publishing the many major results on eigenfrequency statistics in damped systems and the associated effects on response statistics, (and incidentally finishing up the graduate student's PhD) this project has closed. The project's tangential thrust related to diffuse waves on wetted thin shells, is being continued under new auspices as N00014-94-0855.

## D. List of Publications and Invited Presentations of work sponsored by ONR

### Papers published in Refereed Journals

R.L. Weaver, "Diffuse Waves on Submerged Thin Shells," *J.Acoust.Soc.Am.* 95, 857-865 (1994)  *Copy of Paper Attached*

R. Weaver and J. Burkhardt, "Weak Anderson Localization and Enhanced Backscatter in Reverberation Rooms and Quantum Dots," *J. Acoust Soc. Am.*, 12/94 *Copy of Paper Attached*

J. Burkhardt and R. Weaver, papers on eigenstatistics and response statistics in damped systems that are still in preparation *Copy of Thesis and related preprints to be sent later*

### Invited Presentations

R.L. Weaver, "Diffuse radiation from submerged thin shells," paper number 93-WA/NCA-18 (ASME conference paper presented at the Winter Annual Meeting, 1993) *Copy of Paper Attached*

R.L. Weaver, "SEA and apparent damping by a Fuzzy," special presentation at ASME Winter Annual Meeting, 1993

R.L. Weaver, "On Eigenmode Statistics and Power Variances in randomly shaped membranes," *in* Structural Dynamics of Large Scale and Complex Systems, proceedings of the 14th Biennial conference on Vibrations and Noise held in Albuquerque September 1993  editors C.Pierre and N. Perkins,  p 35-42, ASME (1993) *Copy of Proceedings Paper Attached*

R. L. Weaver, "Level Statistics and Enhanced Backscatter in Viscously Damped Reverberation Rooms." Presented to Laboratoire de Physique de la Matiere Condensee, CNRS, Universite de Nice, Nice, France October 1994.

A-1

IN REPLY
REFER TO        DTIC-OCC

SUBJECT: Distribution Statements on Technical Documents

TO:
OFFICE OF NAVAL RESEARCH
CORPORATE PROGRAMS DIVISION
ONR 353
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5660

1. Reference: DoD Directive 5230.24, Distribution Statements on Technical Documents, 18 Mar 87.

2. The Defense Technical Information Center received the enclosed report (referenced below) which is not marked in accordance with the above reference.

**FINAL REPORT**
**N00014-91-J-1873**
**TITLE: EIGENMODE STATISTICS**
**AND PARTIAL COHERENCE IN THE**
**RESPONSES OF COMPLEX**
**STRUCTURES**

3. We request the appropriate distribution statement be assigned and the report returned to DTIC within 5 working days.

4. Approved distribution statements are listed on the reverse of this letter. If you have any questions regarding these statements, call DTIC's Cataloging Branch, (703) 274-6837.

FOR THE ADMINISTRATOR:

1 Encl

GOPALAKRISHNAN NAIR
Chief, Cataloging Branch

FL-171
Jul 93

DISTRIBUTION STATEMENT A:

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

DISTRIBUTION STATEMENT B:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES ONLY;
(Indicate Reason and Date Below). OTHER REQUESTS FOR THIS DOCUMENT SHALL BE REFERRED
TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT C:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES AND THEIR CONTRACTORS;
(Indicate Reason and Date Below). OTHER REQUESTS FOR THIS DOCUMENT SHALL BE REFERRED
TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT D:

DISTRIBUTION AUTHORIZED TO DOD AND U.S. DOD CONTRACTORS ONLY; (Indicate Reason
and Date Below). OTHER REQUESTS SHALL BE REFERRED TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT E:

DISTRIBUTION AUTHORIZED TO DOD COMPONENTS ONLY; (Indicate Reason and Date Below).
OTHER REQUESTS SHALL BE REFERRED TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT F:

FURTHER DISSEMINATION ONLY AS DIRECTED BY (Indicate Controlling DoD Office and Date
Below) or HIGHER DOD AUTHORITY.

DISTRIBUTION STATEMENT X:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES AND PRIVATE INDIVIDUALS
OR ENTERPRISES ELIGIBLE TO OBTAIN EXPORT-CONTROLLED TECHNICAL DATA IN ACCORDANCE
WITH DOD DIRECTIVE 5230.25, WITHHOLDING OF UNCLASSIFIED TECHNICAL DATA FROM PUBLIC
DISCLOSURE, 6 Nov 1984 (Indicate date of determination). CONTROLLING DOD OFFICE IS (Indicate
Controlling DoD Office).

The cited documents has been reviewed by competent authority and the following distribution statement is
hereby authorized.

| _____ (Statement) | OFFICE OF NAVAL RESEARCH CORPORATE PROGRAMS DIVISION ONR 353 800 NORTH QUINCY STREET ARLINGTON, VA 22217-5660 | _____ (Controlling DoD Office Name) |
| _____ (Reason) | DEBRA T. HUGHES DEPUTY DIRECTOR CORPORATE PROGRAMS OFFICE | _____ (Controlling DoD Office Address, City, State, Zip) |
| _____ (Signature & Typed Name) | _____ (Assigning Office) | 19 SEP 1995 _____ (Date Statement Assigned) |